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OPERATION HARDTACK

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PROJECT 2.8

WT-1625 Draft

AIRCRAFT AND ROCKET FALLOUT

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media. Determination of the soluble fraction is therefore an important problem and solubility studies have been reported on fallout from several of the shots at Operations CASTLE and REDWING. For CASTLE fallout, it was found that the soluble fraction was strongly dependent on the detonation environment, being around 0.05 for land shots and 0.58-0.73 for shots fired from a barge (Reference 15). The solubility in seawater of the fallout from the reef shot Tewa, Operation REDWING, was investigated in two ways: by leaching of particles placed on top of a glass wool column and by centrifuging a suspension of the fallout material (Reference 13). The soluble fractions found by these two methods were 0.08 and 0.18, respectively. An ultrafiltration method was used for determining the solubility of fallout from the land shot, Zuni. About 25% of the total gamma activity and Np^{239} were soluble in seawater and 5% of the total gamma activity was soluble in rainwater.

1.2.2 Cloud Development. During the later stages of existence of the fireball, it is transformed into a vortex ring whose rotational velocity persists up to the maximum cloud altitude, at least for the larger shots. The vortex contains the fission products, environmental material and bomb components which were present in the fireball and is the site where the radioactive fallout particles are generated. The cloud continues to rise until its buoyancy is reduced to zero by adiabatic expansion, entrainment

of cold air and loss of energy in overcoming atmospheric drag (References 16, 17, 18). The diameter of the ring increases rapidly during the ascent and the cloud spreads out laterally to a large area as its upward velocity decreases. For smaller yields the cloud stops at the tropopause or below, but for megaton-range weapons the top may penetrate several thousand feet into the stratosphere. The time to maximum altitude is somewhat less than ten minutes.

A knowledge of the distribution of activity and particles within the stabilized cloud is needed for the establishment of a rational fallout model; however, the collection of a suitable set of samples which could be used to determine these quantities experimentally presents a formidable operational problem which has not yet been solved. Several distributions have been assumed in an effort to match the fallout patterns on the ground, but it is not known how closely these models correspond to the actual structure of the cloud. Considering the method of formation, it might perhaps be anticipated that the activity would be greatest in an anchor ring centered on the axis of the cloud. Some evidence for this structure was obtained at Operation REDWING with rockets with telemetering ionization chambers (Reference 19).

<u>1.2.3 Transport and Distribution.</u> During the ascent of the nuclear cloud the particles present are acted on by body forces and by the vertical

currents in the rising air. Some of the large particles will be heavy enough so that they will have a net downward velocity even though the cloud as a whole is moving upward. They will contribute to the fallout in the immediate vicinity of ground zero (Reference 20).

Once the upward motion has ceased, the particles in the cloud will begin to settle out at rates determined by their density, dimensions and shapes and by the viscosity and density of the air (Reference 21). The terminal velocities for small spheres can be accurately calculated when the dependence of the drag coefficient on Reynold's number is known. Irregular or angular particles will fall more slowly than spheres of the same weight, but their velocities cannot be estimated as well due to uncertainty in the shape factors (Reference 22).

The particles which make up the local fallout follow trajectories to the surface governed by their fall rates and by the mean wind vector between their points of origin in the cloud and the ground level. Locations can be specified by reference to a surface coordinate system made up of height lines and size lines. The height lines are the loci of the points of arrival of all particles originating at given heights on the axis of the cloud. The size lines connect the arrival points of particles of the same size from different altitudes. Time and space variation of the winds will change the magnitude and direction of the mean wind vector, and vertical motions

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27, 28), TUMBLER-SNAPPER (References 27, 16), UPSHOT-KNOTHOLE (References 16, 27), CASTLE (Reference 29, 30, 31, 32, 33), WIGWAM (Reference 34), TEAPOT (Reference 35), and REDWING (References 23, 36). A summary of values computed from gamma contours and/or area sampling covered a range from 0.2 to 0.6 (References 25, 26). Re-examination of the preliminary REDWING data by Tucker (Reference 37) gave higher figures in the range 0.65-0.70 for barge (water surface) shots and up to 0.85 for land surface shots.

Results by the UCRL cloud sampling method are also available from REDWING (Reference 26) for the ground shots Lacrosse, Mohawk, Zuni and Tewa (part land, part water), for the water surface shots Huron and Navajo, and the high altitude air burst, Cherokee. In the first three events the ratio of solid-to-gas fissions was as low as 0.04. Values for Tewa were not much less than one but this was probably due to the low sampling altitudes relative to cloud height. The ratios for the barge shots were greater than 0.6 in all cases. For Shot Cherokee the single sample measured gave a ratio of one. Interpretation of these figures in terms of fallout distribution indicates that 90-95% of the activity came down locally for the land shots, 15-50% for the water shots, and essentially none for the high altitude air burst.

On 5-7 March 1957 a symposium was held at the Rand Corporation

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in water samples collected from the ocean surface near the site of detonation

little fractionation was found for the one device detonated in deep water (Reference 34).

At Operation GREENHOUSE it was noted that the exponent of the beta decay curve increased from 0.95 to 1.3 with median particle size for samples taken from the clouds at Dog, Easy and Able shots. This indicates that the close-in particles are enriched in fast decaying components with respect to the more distant fallout (Reference 53).

For JANGLE surface shots, pronounced depletion of chains 89, 115, 111 and 140 referred to Mo^{99} was observed in comparing long-range with local fallout samples. Chains 144 and 95 were not fractionated. Still more extensive nuclide separation was found for the underground shot with all the above chains showing depletion in the crater area (Reference 53).

On Shot 6 at TUMBLER-SNAPPER the gross decay exponent decreased steadily with distance from ground zero up to seventy miles (Reference 53).

Radiochemical data from CASTLE Brave showed fractionation of Sr^{90} and Ba^{140} with respect to Mo^{99}, but none for Ce^{144} (Reference 53).

In the land Shots Zuni and Tewa of Operation REDWING, depletion of Cs^{137}, Sr^{90}, and Te^{132} was found in the close-in fallout with maximum factors of 100, 13 and 7 (Reference 54). These depletion factors became smaller with increasing distance from the shot point. Fractionation of the

CHAPTER II

PROCEDURE

2.1 SHOT PARTICIPATION

The project initially planned to participate in Shots Koa, a megaton-range land-surface burst, and Walnut, a DELETED water-surface burst. Due to apparent contamination of the Koa cloud samples by debris from Shot Fir, participation was later extended to include Shot Oak, a high-yield water-land burst fired over the lagoon reef. Important device information is given in Table 2.1. The project rockets participated during Shots Koa and Walnut and were also fired during Cactus and Yellowwood for system check and nose cone recovery practice. Aircraft were flown during Koa, Walnut and Oak.

TABLE 2.1

DEVICE INFORMATION

	KOA	WALNUT	OAK
Total Yield, Mt.:	1.31 ± 0.08	DELETED	8.9 ± 0.6
Fission Yield, Mt.:	DELETED		LETED
Location	Site Gene	Near Site Janet	4 miles south of Site Alice
Shot time	0630 M 13 May 1958	0630 M 15 June 1958	0730 M 29 June 1958
Shot type	Land-Surface	Water-Surface; fired from a barge in deep water	Water-Land Surface; fired from an LCU anchored over the lagoon reef in 15 feet of water

are calculated from R-values averaged throughout the cloud for the first four hours. The fractions for Oak are also from averages, here in the light and variable stratum, while for Walnut the stabilized condition shown in Figure 3.1 is used. Sample 980 L for Oak is not included due to the poor sampling conditions.

The fractions of these nuclides remaining in the cloud after one day are given in Table 3.2. These numbers are to be interpreted as the quantity of material which does not come down in the local area. The limits assigned are derived from the variability in the data.

PERCENT

TABLE 3.2

~~FRACTIONS~~ OF NUCLIDES LEFT IN CLOUD AFTER ONE DAY

	Mo^{99}	Sr^{90}	Cs^{137}
Koa	4^{+4}_{-0}	20	64
Walnut	30 ± 5	41	78
Oak	15 ± 10	45	61

Of the curves for the fraction of Mo^{99} left in the clouds, the one for the water surface burst shows to a considerable degree the behaviour anticipated when the project was planned. On the reef shot, the points appear to be fluctuating around a fraction of 0.15, whereas for the land surface detonation there is insufficient data to do anything but extrapolate beyond 6.5 hours. Since it is likely that the fission ratios would be around one

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TABLE 3.3

Sr^{90} AND Cs^{137} R-VALUES VS ALTITUDE

KOA				WALNUT				OAK			
Sampling Altitude, Feet	Sampling Time Hrs.	$R^{99}(90)$	$R^{99}(137)$	Sampling Altitude, Feet	Sampling Time, Hrs.	$R^{99}(90)$	$R^{99}(137)$	Sampling Altitude, Feet	Sampling Time Hrs.	$R^{99}(90)$	$R^{99}(137)$
39,000*	3	0.47	1.37	42,000	2.5	0.75	1.00	45,500	3.9	0.29	0.46
40,000	2.3	0.72	0.59	44,000	3.1	1.27	1.94	47,000	2.8	0.30	0.42
45,000	2.75	1.32	3.05	48,000	3.15	1.39	2.02	49,000	3.25	0.41	0.42
45,000*	3.5	0.69	3.20	50,000	3.7	1.49	2.17	54,000	3.75	0.52	0.63
49,000	3.0	0.77	0.71	57,500	1.6	1.07	1.77	56,400	2.1	1.72	3.67
56,000	6.5	1.37	3.85	58,000	3.4	0.94	1.33	55,000*	2.1	1.23	4.82
56,000*	6.5	1.40	4.44	64,000(?)	6.8	1.08	1.69	64,000(?)	3.2	2.32	5.48
60,000	7.3	7.76	39.0	57,800	12.3	1.18	1.81	56,300	6.0	3.15	7.50
60,000*	8	7.06	33.8	58,500	27.5	1.16	1.84	56,300	12.3	3.24	7.21
60,000*	11	8.30	46.2					55,000	26.8	1.32	2.04
60,600	4.5	5.62	27.8					55,000*	26.8	1.56	2.02
60,600*	4.5	10.50	38.08								
Device		0.77	0.90			0.77	0.90			0.77	0.90

*Calculated as gross figures from the R-values for the size-separated fractions.

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fallout.

On the reef shot it appears that the sampling planes were just entering the base of the cloud at the 55,000 foot level since there is a sudden jump in the R-values at this point. The material collected at lower altitudes is depleted in both Sr^{90} and Cs^{137} and is not greatly different in composition from the fallout at 1000 feet. It is also noted that the enrichment factors for both nuclides go through a maximum with time for the samples from the light and variable stratum. This might be interpreted as indicating a concentration on particles of some size intermediate between the early and late fallout from this region.

Somewhat similar data for the Mo^{99}-to-Kr^{88} and Kr^{88}-to-Kr^{85} ratios for the first four hours following detonation are given in Table 3.4. The Mo^{99} to Kr^{88} ratios are also shown graphically in Figure 3.4. At the lower altitudes the Mo^{99} is enriched and the Kr^{88} depleted with respect to Kr^{85}.

3.1.2 Fallout Data. The radiochemical data on the fallout samples may be used to obtain results for the distribution of Sr^{90} and Cs^{137} which are complementary to those found from the cloud analyses. The fraction of the total Mo^{99} formed in the explosion which has left the cloud is found by difference from the numbers given in Table 3.2. Multiplication of these figures by the Sr^{90} and Cs^{137} R-values for the fallout and division

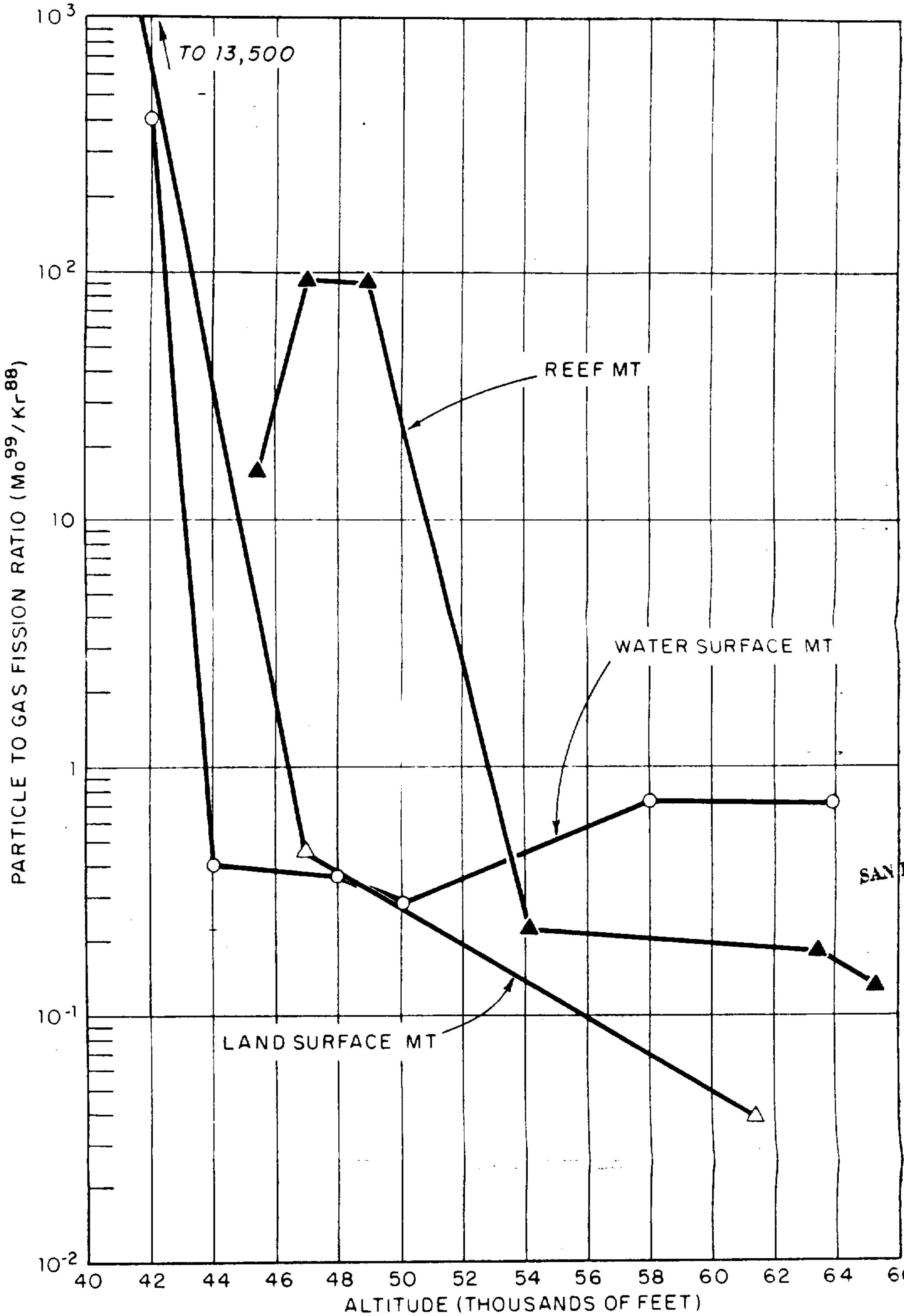

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FIG. 3.4

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TABLE 3.4

Mo-TO-Kr AND Kr^{88}-TO-K^{85} RATIOS FOR FIRST FOUR HOURS, SHOT KOA

Sample No.	Sampling Time, hrs	Sampling Altitude, Feet	Mo^{99}/Kr^{85}	Mo^{99}/Kr^{85m}	Mo^{99}/Kr^{88}	Kr^{88}/Kr^{85m}	Kr^{88}/Kr^{85}
502 R	2.5	41,000	192.9	270.0	13,500	0.02	0.014
500 L	3.5	47,000	0.32	0.49	0.44	1.11	0.73
500 R	3.5	47,000	---	---	0.98	---	---
977 R	3.75	61,500	---	0.052	0.038	1.38	---

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TABLE 3.4, CONT'D

Mo-TO-Kr AND Kr^{88} TO Kr^{85} RATIOS FOR FIRST FOUR HOURS, SHOT WALNUT

Sample No.	Sampling Time, hrs	Sampling Altitude, Feet	Mo^{99}/Kr^{85}	Mo^{99}/Kr^{85m}	Mo^{99}/Kr^{88}	Kr^{88}/Kr^{85m}	Kr^{88}/Kr^{85}
501 L	2.5	42,000	2.14	3.44	420.8	0.0082	0.00508
504 L	3.1	44,000	0.66	0.60	0.41	1.47	1.63
504 R	3.1	44,000	0.59	---	---	---	---
496 L	3.15	48,000	0.61	0.53	0.36	1.47	1.69
496 R	3.15	48,000	0.46	0.54	0.38	1.43	1.21
500 R	3.7	50,000	0.47	0.43	0.28	1.52	1.66
982 L	1.6	58,000	0.72	0.67	0.73	0.92	0.98
982 R	1.6	58,000	0.73	0.59	0.70	0.84	1.04
980 L	3.4	58,000	0.60	0.50	0.71	0.71	0.84
980 R	3.4	58,000	0.65	0.54	0.73	0.73	0.88

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TABLE 3.4, CONT'D

Mo-TO-Kr AND Kr^{88} TO-Kr^{85} RATIOS FOR FIRST FOUR HOURS, SHOT OAK

Sample No.	Sampling Time, hrs	Sampling Altitude, Feet	Mo^{99}/Kr^{85}	Mo^{99}/Kr^{85m}	Mo^{99}/Kr^{88}	Kr^{88}/Kr^{85m}	Kr^{88}/Kr^{85}
501 L	3.9	45,500	1.67	---	---	---	---
501 R	3.9	45,500	1.45	1.21	15.3	0.079	0.095
504 L	2.8	47,000	4.48	4.63	95.0	0.049	0.047
504 R	2.8	47,000	3.08	--	--	--	--
496 L	3.25	49,000	5.29	5.00	92.5	0.054	0.057
496 R	3.25	49,000	4.52	--	--		
495 L	3.75	54,000	1.85	1.51	2.19	0.69	0.84
978 L	2.1	56,400	0.15	0.15	0.11	1.36	1.40
978 R	2.1	56,400	0.19	0.18	0.14	1.25	1.31
981 R	3.2	?	0.25	0.21	0.18	1.18	1.39

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by the device R-values convert them to fractions of the two nuclides in the fallout. Table 3.5 lists results obtained in this way based on the averaged composition for the fallout.

TABLE 3.5

DATA ON NUCLIDES IN FALLOUT

	R-Value(Average)		Fraction Deposited		
	Sr^{90}	Cs^{137}	Mo^{99}	Sr^{90}	Cs^{137}
Koa	0.52	0.44	0.96	0.65	0.47
Walnut	0.78	1.13	0.70	0.71	0.88
Oak	0.45	0.40	0.85	0.49	0.37

The sum of the nuclide fractions from the cloud and fallout should be one in each case provided that the R-values used are representative of the cloud and fallout as a whole. This seems to be likely for the fallout where the R-values change only relatively slightly with time but more doubtful in the cloud due to the scatter of the analytical results. Table 3.6 gives a comparison between the deposited and airborne fractions. The agreement is perhaps generally as good as could be expected considering the nature of the data.

All the samples from the land and reef shots show depletion of both Sr^{90} and Cs^{137} as compared to the detonation yields. This is most pronounced in the earliest samples. Material coming down at times later than

TABLE 3.6

COMPARISON OF AIRBORNE AND DEPOSITED FRACTIONS

	Sr^{90}			Cs^{137}		
	Fraction Deposited	Fraction Airborne	Total	Fraction Deposited	Fraction Airborne	Total
Koa	0.65	0.20	0.85	0.47	0.64	1.11
Walnut	0.71	0.41	1.11	0.88	0.78	1.66
Oak	0.49	0.45	0.94	0.37	0.61	0.98

4 hours for the land shot, and 6 hours for the reef shot, is quite uniform in composition and exhibits little evidence of fall rate-dependent fractionation. Sr^{90} is generally more depleted in the reef shot than the land shot, while the reverse is true for Cs^{137}.

The 4-hour fallout from the water surface shot is depleted in both nuclides, but the 10-and 13-hour samples show an enrichment. The two latter samples have nearly the same composition. The failure of the 6-and 8-hour flight missions makes the data rather scanty in this case.

These effects are brought out clearly by the numbers listed in Table 3.7.

3.1.3 Combined Cloud and Fallout Data. Another way of estimating the fraction of Mo^{99} left in the cloud, independent of the fission ratios, is based on a material balance for some nuclide, Y. R-values for nuclide Y

TABLE 3.7

ENRICHMENT FACTORS IN FALLOUT

KOA Sample No.	KOA Sampling Time, hrs	KOA R_1	KOA R_2	WALNUT Sample No.	WALNUT Sampling Time, hrs	WALNUT R_1	WALNUT R_2	OAK Sample No.	OAK Sampling Time, hrs	OAK R_1	OAK R_2
Massive L1	4	0.62	0.37	Massive 1 R1	4	0.68	0.63	Massive R1	4	0.58	0.20
Massive R2	6	0.68	0.54	Massive 2 R1	10	1.25	1.57	Massive R2	6	0.49	0.24
Massive R3	8	0.68	0.54	Massive 2 R2	13	1.13	1.57	Massive R3	8	0.63	0.59
Massive R4	10	0.68	0.52					Massive R4	10	0.63	0.61
Massive R5	12	0.70	0.50					Massive R5	12	0.60	0.58
Wilson Sp. R	6	0.69	0.48								

$$R_1 = \left[R^{99}(90)\right]_{FO} : \left[R^{99}(90)\right]_{E} = \frac{\text{Ratio of } Sr^{90} \text{ to } Mo^{99} \text{ observed in fallout}}{\text{Ratio of } Sr^{90} \text{ to } Mo^{99} \text{ expected from the device}}$$

$$R_2 = \left[R^{99}(137)\right]_{FO} : \left[R^{99}(137)\right]_{E} = \frac{\text{Ratio of } Cs^{137} \text{ to } Mo^{99} \text{ observed in fallout}}{\text{Ratio of } Cs^{137} \text{ to } Mo^{99} \text{ expected from the device}}$$

[redacted]

TABLE 3.9[a]

CLOUD DATA, OPERATION REDWING

Land Shot (Zuni)			Reef Shot (Tewa)			Water Shot (Navajo)		
Altitude, feet	$R^{99}(90)$	$Mo^{88}:Kr^{88}$	Altitude, feet	$R^{99}(90)$	$Mo^{99}:Kr^{88}$	Altitude, feet	$R^{99}(90)$	$Mo^{99}:Kr^{88}$
41,000	0.51	50.0	32,000	0.44	16.6	39,000	0.75	14.3
51,000	0.64	2.5	48,000	0.47	14.3	43,000	0.64	100.0
55,000	2.0	0.11	51,000	0.86	0.77	46,000	0.68	100.0
			53,000	1.5	0.59	50,000	---	0.54

a. Reference 26.

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corrected R-values from Redwing are listed in Table 3.10; for the land surface and reef shots, cloud and close-in fallout values are given to show the range.

TABLE 3.10

FRACTIONATION-CORRECTED R-VALUES FOR REDWING

	$R^{99}(90)$			$R^{99}(137)$		
Shot	Cloud	Close-in	Average	Cloud	Close-in	Average
Water Surface, KT	--	--	0.34	---	---	0.32
Water Surface, MT	--	--	~1.0	---	---	~1.0
Reef, MT	~ 1.0	0.078	--	~1.0	0.03	--
Land Surface MT	2.3	0.078	--	1.8	0.03	--

3.4 EFFECTIVENESS OF INSTRUMENTATION

The aircraft-borne sampling equipment performed in a generally satisfactory manner throughout the entire operation with the exception of some malfunctioning of the gas compressor pumps on the first shot. This was due primarily to the shortage of time for checkout prior to actual operational use. As the participating personnel gained experience, communications improved and the sampling flights progressed more smoothly. Each of the three types of aircraft sampling equipment is considered to be well suited for its intended use.

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APPENDIX C

PARTICLE DATA AND CHARACTERISTICS, SHOT KOA

C.1 Size Distribution, Fall Rate and Specific Activity Data

Fall rate distribution data, particle size data and specific activity-fall rate data are presented in graphical form, in Figures C.1 through C.13, for the cloud and fallout samples listed in Table C.1. Samples 500, 502 and 977 from the cloud were separated into coarse and fine fractions with the Bahco centrifuge before determination of the distribution curves. The boundary between the centrifuge fractions is as given in Appendix B. No fall rate work was done on samples taken from the cloud at times later than four hours due to the small quantity of material collected.

TABLE C.1

Sample List

Fall Rate Distribution	Particle Size Distribution	Specific Activity
Massive L1	Massive L1	Massive L5
Massive L2	Massive L4	Wilson Special
Massive L3	502 Coarse	502 Coarse
Massive L4	502 Fine	502 Fine
Massive L5	500 Coarse	500 Coarse
Wilson Special	500 Fine	500 Fine
502 Coarse	977 Coarse	977 Coarse
502 Fine	977 Fine	977 Fine
500 Coarse		
500 Fine		
977 Coarse		
977 Fine		

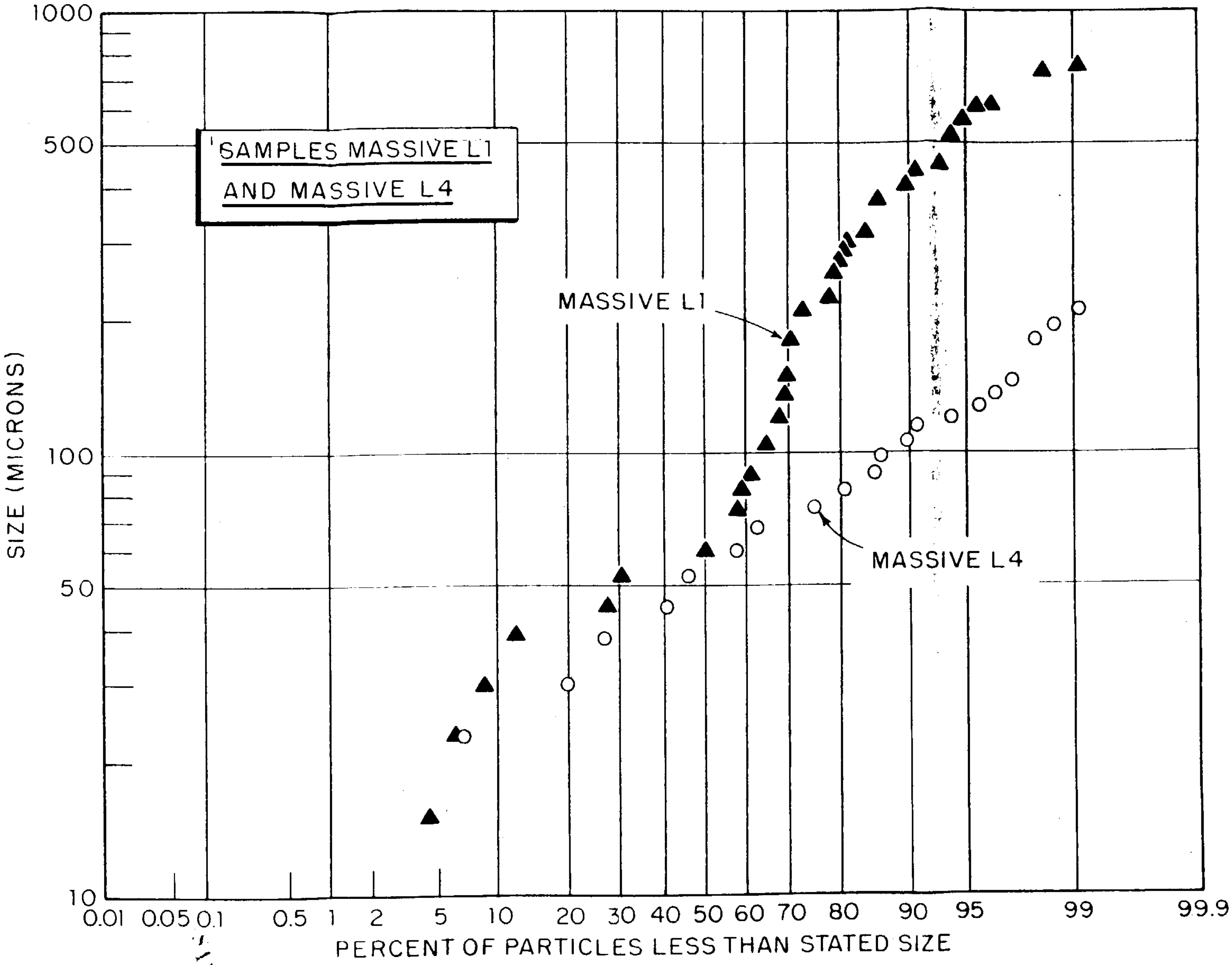
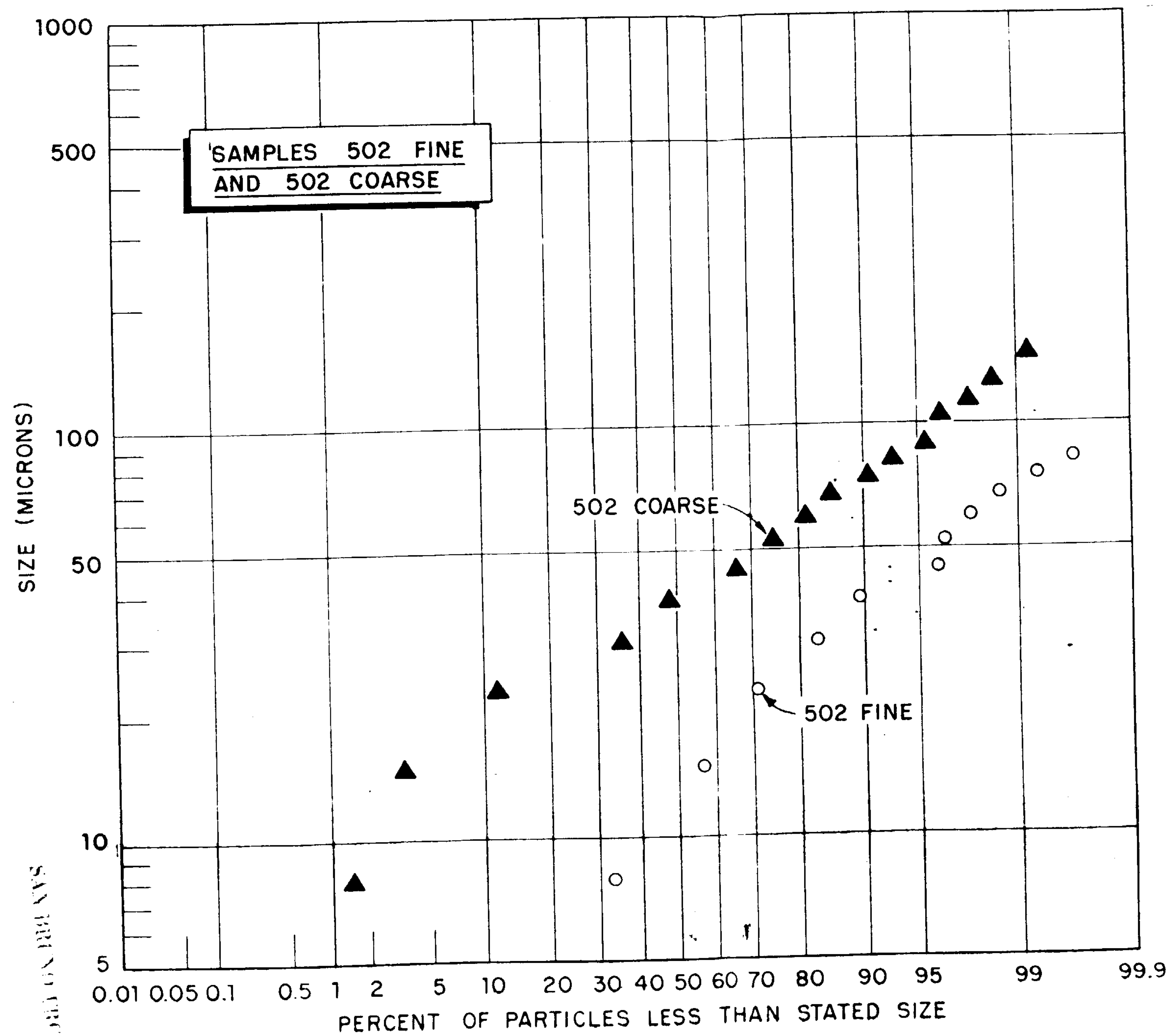
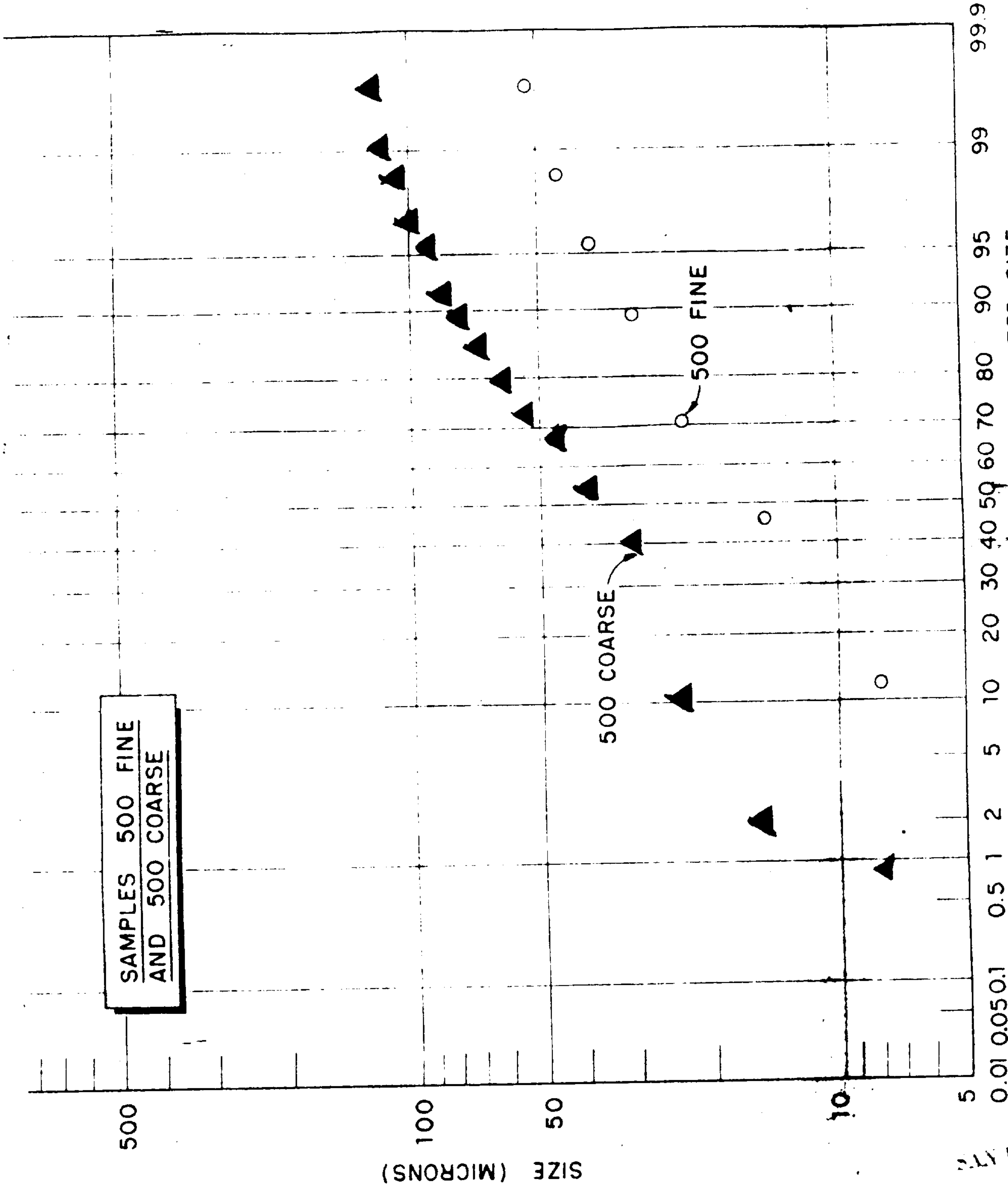

SAMPLES MASSIVE L1
AND MASSIVE L4
MASSIVE L1
MASSIVE L4
SIZE (MICRONS)
1000
500
100
50
10
PERCENT OF PARTICLES LESS THAN STATED SIZE
0.01 0.05 0.1 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 99 99.9

FIG. 2.10


SAMPLES 502 FINE
AND 502 COARSE
502 COARSE
502 FINE
SIZE (MICRONS)
1000
500
100
50
10
5
0.01 0.05 0.1 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 99 99.9
PERCENT OF PARTICLES LESS THAN STATED SIZE



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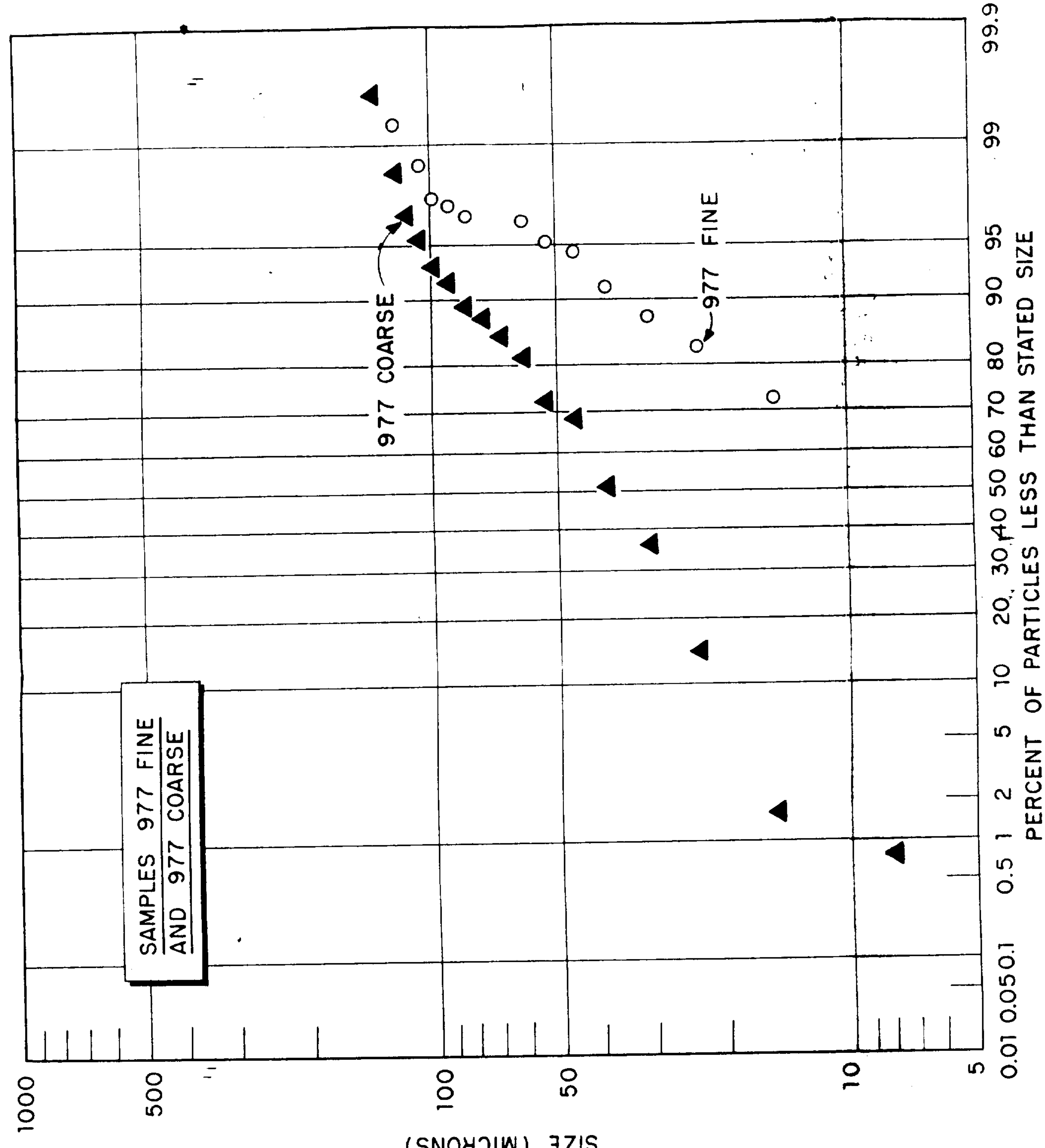
SAMPLES 977 FINE
AND 977 COARSE
977 COARSE
977 FINE
PERCENT OF PARTICLES LESS THAN STATED SIZE
0.01 0.05 0.1 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 99 99.9
SIZE (MICRONS)
1000 500 100 50 10 5

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